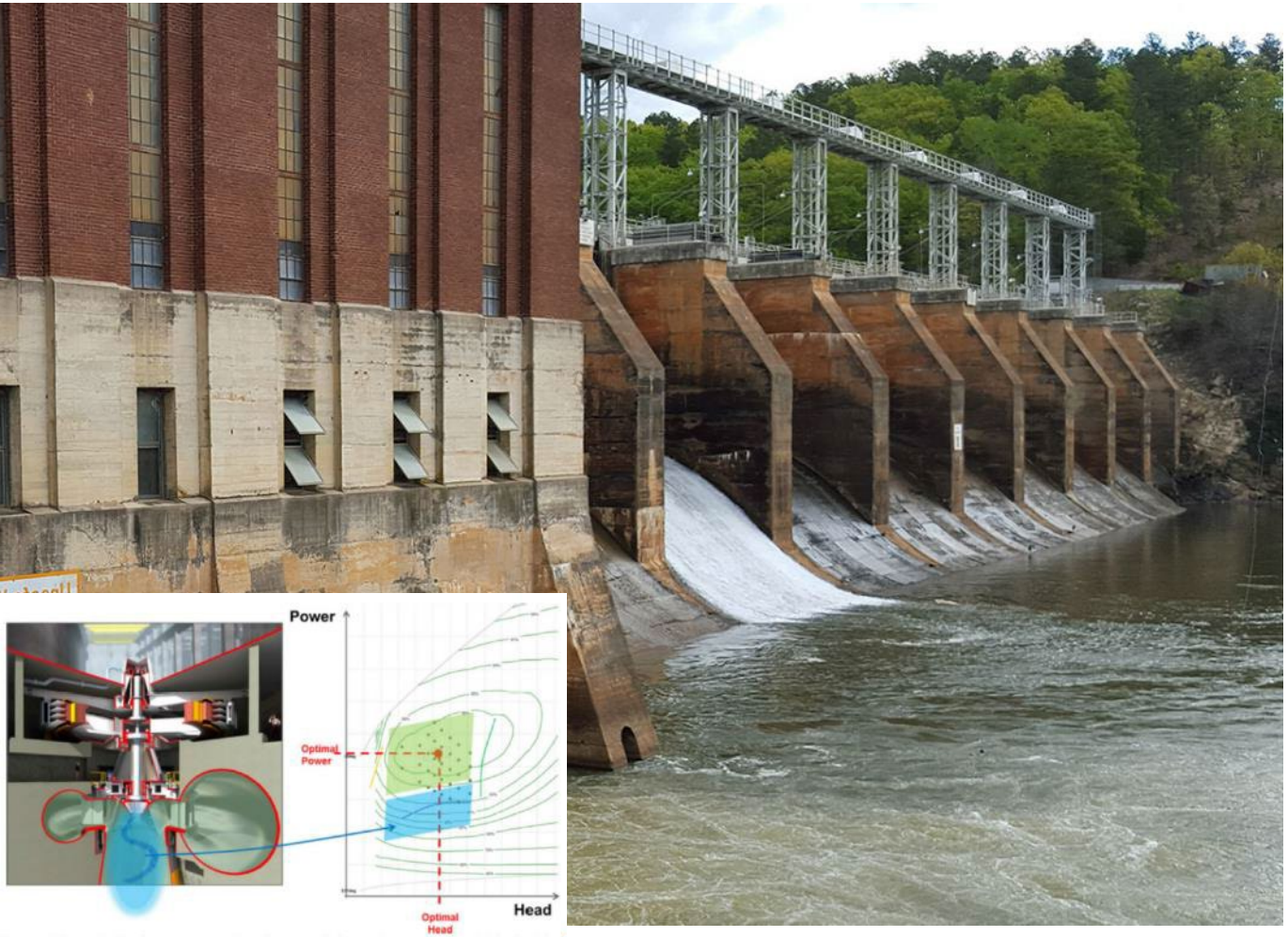
DE-EE0008942 – Increasing Operational Flexibility of Francis Turbines at Low Head Sites, Through Analytical and Empirical Solutions



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GE Research
GE Renewable Energy
EAGLE CREEK RENEWABLE ENERGY

Project Overview

Project Summary

DE-EE0008942 aims to demonstrate the untapped flexibility potential of low-head Francis hydropower fleet and the methodology to tackle it through an extension of the usual turbine operating range.
This increased flexibility will enable these plants to generate power over a wider operating range and to contribute to grid system resilience and reliability.
The proposed approach based on analytical and empirical solutions will be implemented for demonstration on the High Rock* powerplant, operated by Eagle Creek Renewable Energy. Then a grid simulation will evaluate the impact of hydro fleet additional flexible capabilities on frequency response of the WECC grid on a typical « worst case scenario »

**High Rock powerplant, NC, Eagle Creek RE, 3x 13MW, Francis-driven units, 17m head, built in 1927 and retrofitted in 2020, Dissolved Oxygen management capability (air injection)*

Intended Outcomes

- Demonstration on the High Rock site of the feasibility and robustness of the proposed approach and its toolset
- Recommendation of operating strategies to reach an operating range extension on High Rock plant
- Quantification of grid benefit from increased flexible capabilities of Francis-driven hydropower plants
- Reports & showcase demonstrating the flexibility potential of low-head francis hydropower fleet, the tools to tackle it and its impact for the grid – towards plant owners, grid designers, regulation authorities

Project Information

Principal Investigator(s)

- Dr. Miaolei Shao, GE Research

Project Partners/Subs

- GE Research
- GE Renewable Energy
- Eagle Creek Renewable Energy

Project Status

Sunsetting

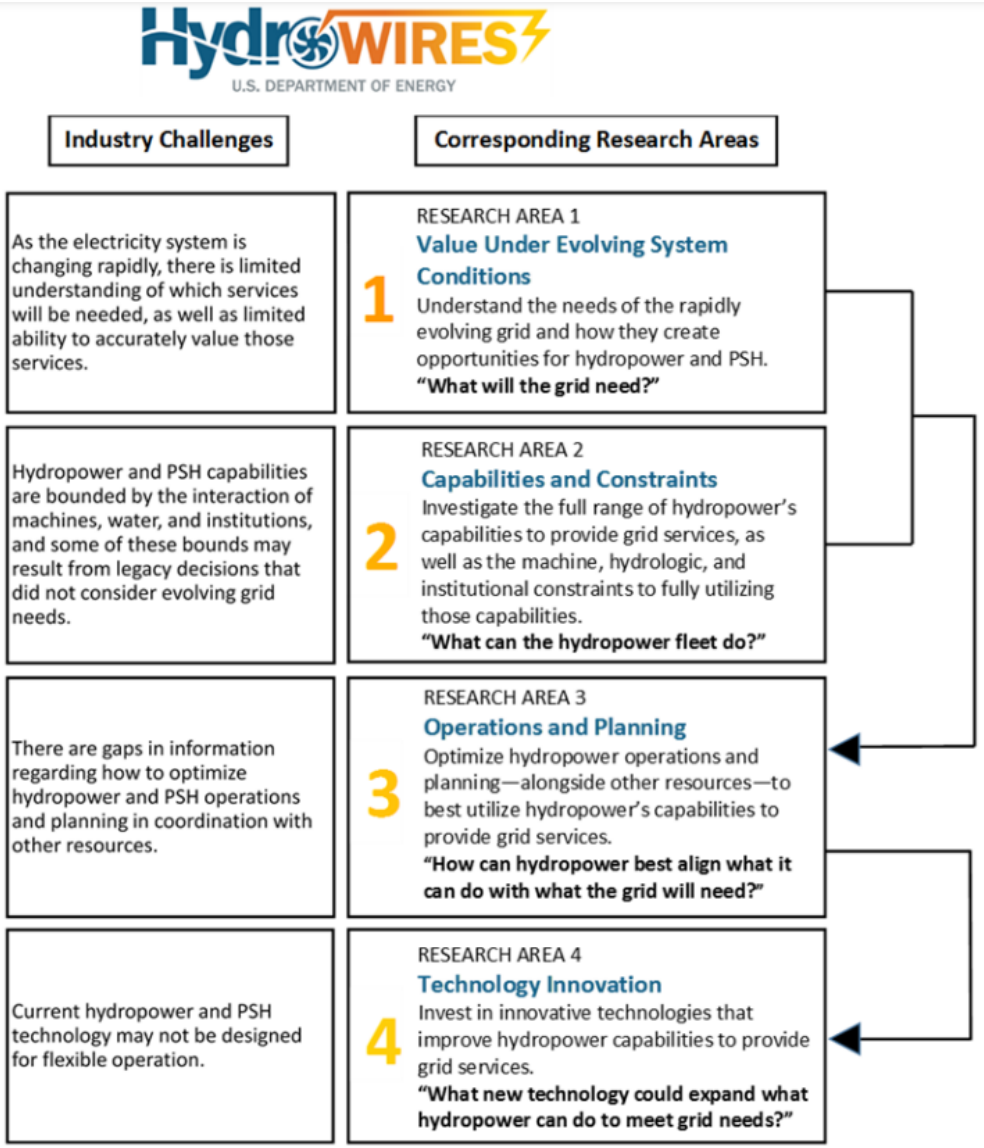
Project Duration

- Jan. 2020
- Aug. 2022

Total Costed (FY20–FY21)

1.283 $K

Project Objectives: Relevance



1 *What will the grid need ?*

- ✓ Simulate the impact of the proposed enhanced flexibility to support WECC grid reliability and resilience on a typical « worst case scenario »: *2028 light spring load with high wind and solar*

2 *What can the hydro fleet do ?*

- ✓ Assess untapped headroom (potential operating range extension)
- ✓ Assess low head Francis existing fleet capability thanks to the analysis of a typical plant (High Rock, NC): mature vs new design, air admission

3 *How can hydro best align what it can do with what the grid will need ?*

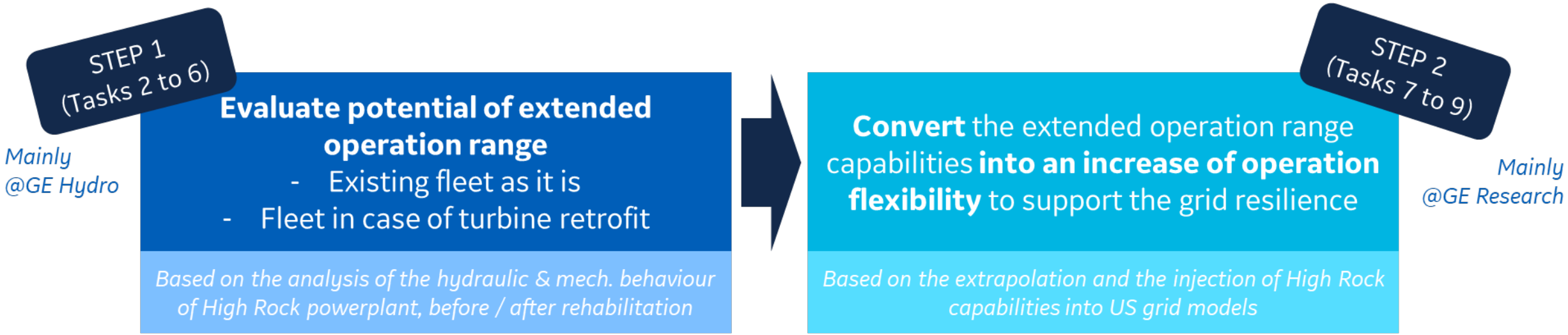
- ✓ Propose operating range extension
- ✓ Investigate innovative operational strategies

4 *What new technology could expand what hydro can do to meet grid needs ?*

- ✓ Methodology for operating range extension, incl. advanced innovative tools
- ✓ New designs for extended operated range

Project Objectives: Approach

- Approach structured in 2 main steps :



- The project offers the 1st evaluation of the operating range extension capabilities of a low-head Francis power plant. It has already been achieved and documented on several power plants over the last few years, but never on low-head sites (more prone to unsteady hydraulic phenomena).

Project Objectives: Expected Outputs and Intended Outcomes

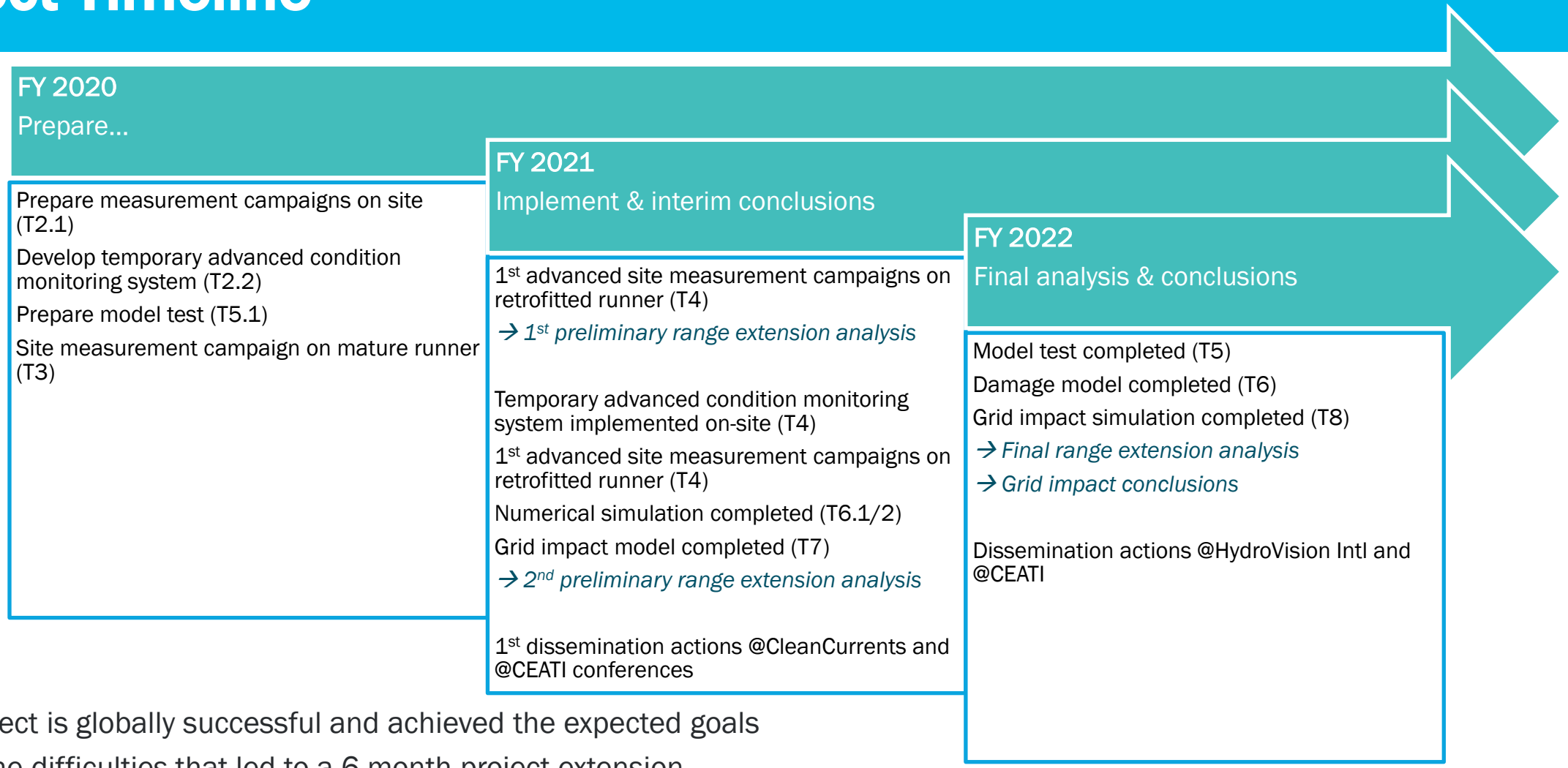
Outputs:

- Reports demonstrating the flexibility potential of low head Francis hydropower plants
  - Methodology to tackle this potential
  - Example on a typical plant, High Rock
- Recommendation of operating range extension on High Rock plant
- Quantification of grid benefit from increased flexible capabilities of Francis-driven hydropower plants

Outcomes:

- Headroom almost doubled for High Rock site
- Simulation of the improved grid frequency response from low head Francis unit extended flexible capabilities
- The plant owners aware of this potential and the tools to tackle it… so that they integrate range extension analysis in their investment forecasts
- The regulators & public authorities will be aware of this potential… so that they acknowledge the related value in the regulatory context and support technological improvements for a wider dissemination (other plants/head/size…)

Project Timeline



- Project is globally successful and achieved the expected goals
- Some difficulties that led to a 6-month project extension
  - Manage developments & site tests during COVID pandemic (travels, shipments, procurement)
  - Difficulties in the onboard acquisition system development
  - Difficulties in the manufacturing of the model runner (1st of a kind: connected and additive manufacturing in metal)

Project Budget

Total Project Budget – Award Information		
DOE	Cost-share	Total
1’000$K	250$K	1’250$K

FY20	FY21	FY22	Total Actual Costs FY20–FY22
Costed	Costed	Costed	Total Costed
869$K	414$K	TBD (ongoing	1.283$K

- COVID pandemic and technical difficulties led to budget slippages backed by GE Renewable Energy (cost share increase)
- Mitigation actions were proposed along the project to preserve the outcomes and attenuate slippages
  - 2nd campaign performed onsite after the unsatisfactory 1st one,
  - remotely-driven actions (gauges implementation, advanced monitoring parameterization…),
  - release of interim conclusions to enable grid simulation,
  - scope transfer from GE Research to GE Renewable Energy (Hydro technology headquarter, France)
  - increase test plan for the model test to deepen the investigation based on site feedback

End-User Engagement and Dissemination

- Inform the industry stakeholders that the Francis units of low head hydro fleet represent an **affordable and sustainable reservoir of flexibility**
  - Make the plant owners aware of this potential and the tools to tackle it
  - Make the TSO aware of the hydro potential : volume addressable, cost & leadtime to mobilize it
  - Make the regulation authorities aware of this potential and the regulatory barriers to rule out

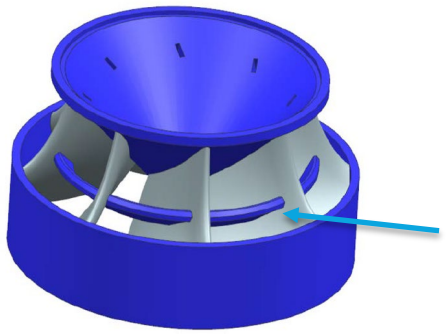
- The High Rock demonstration (real & typical site) showcases this potential

- The dissemination started in 2021 with plant owners presenting preliminary results (“teaser”) and will accelerate after the project completion (mid-2022)
  - Joint presentation GE-ECRE at technology-oriented hydro-industry conferences (HydroVision Intl, CEATI, CleanCurrents)
  - Webinars towards plant owners

- The support from Hydrowires initiative would be impactful to approach TSOs and regulation authorities
  - Potential release of a whitepaper
  - One-to-one discussions with key stakeholders of the US electricity grids & markets

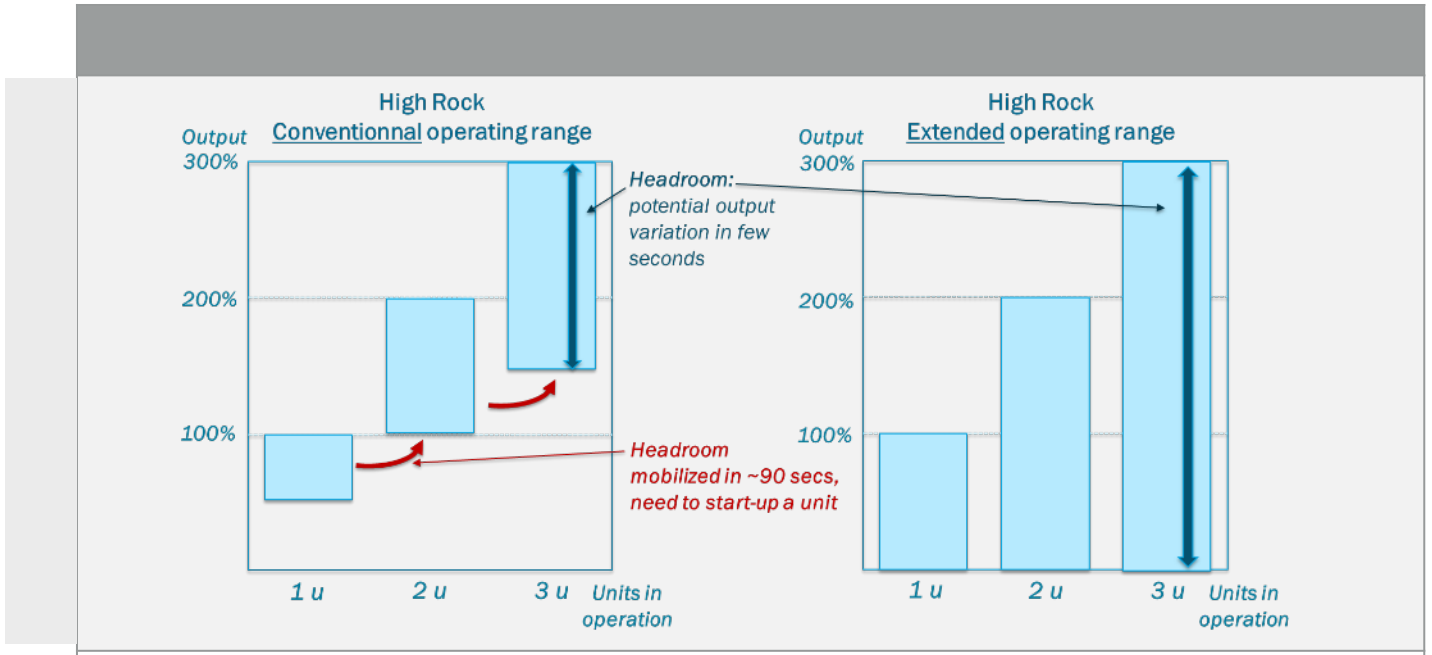
Performance: Accomplishments and Progress

- Demonstration of **a massive operating range extension capability** on High Rock site (doubled) with a **new design** of runner and adequate **air injection strategy**

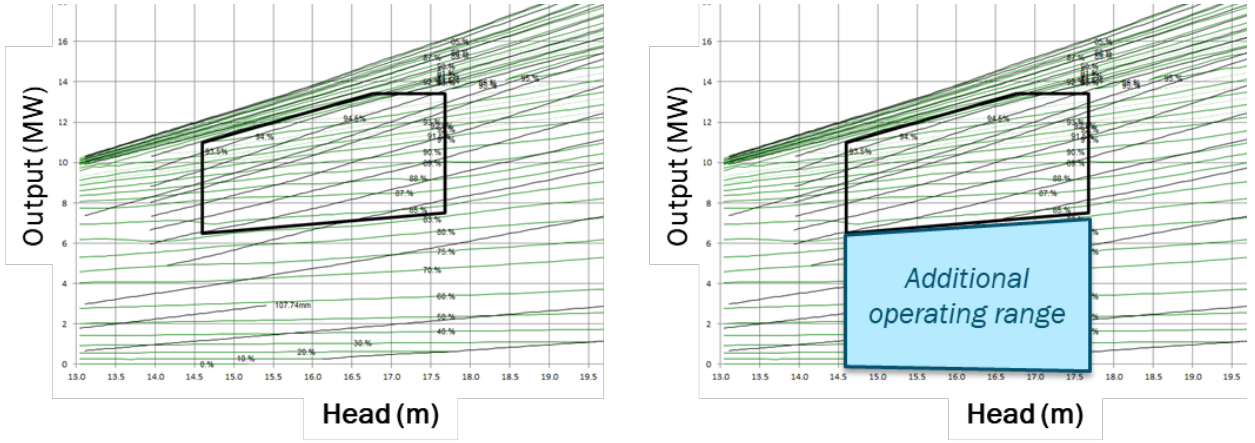


Dissolved-Oxygen (DO) design for Francis runners with Interblade airfoil introducing air at leading edge, improving DO for less air injected

- *As High Rock is a typical low head Francis-driven plant (recently retrofitted and offering dissolved oxygen regeneration capabilities), the project highlight the flexibility potential that represents the whole low head Francis fleet*

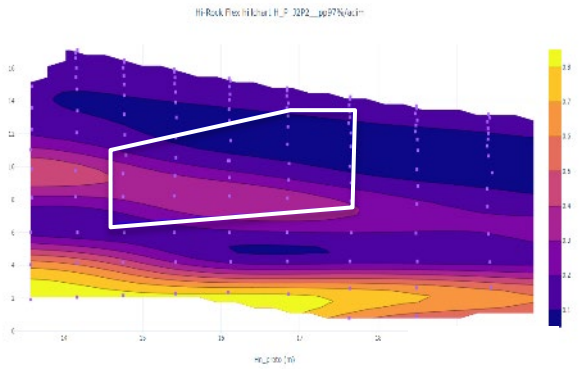


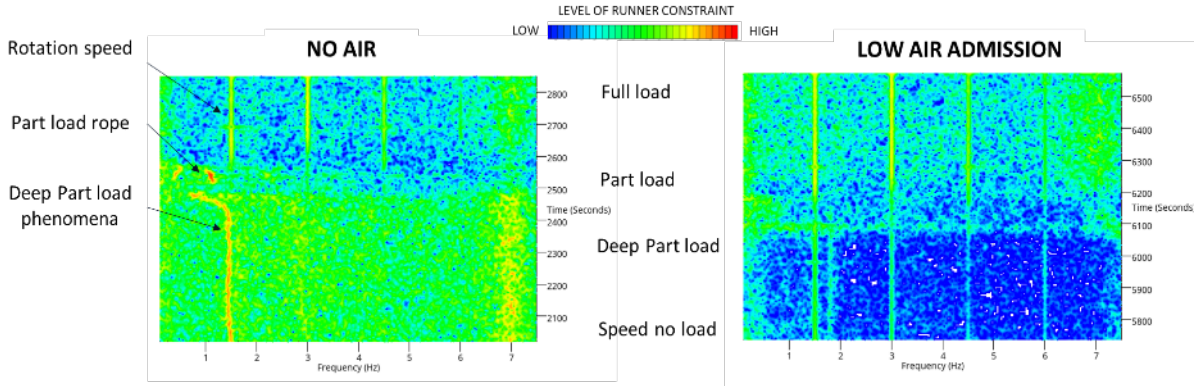
Operating range



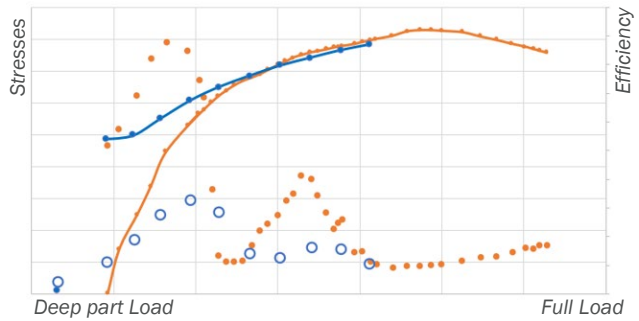
Performance: Accomplishments and Progress

- Analysis of the hydraulic & mechanical behavior of High Rock turbine
  → air admission (axial & distributed) can kill the impact of the unsteady hydraulic phenomena and thus enable to operate at low load





Spectral analysis of the stress levels measured on a runner blade with / without air admission
(site tests, Apr.21)

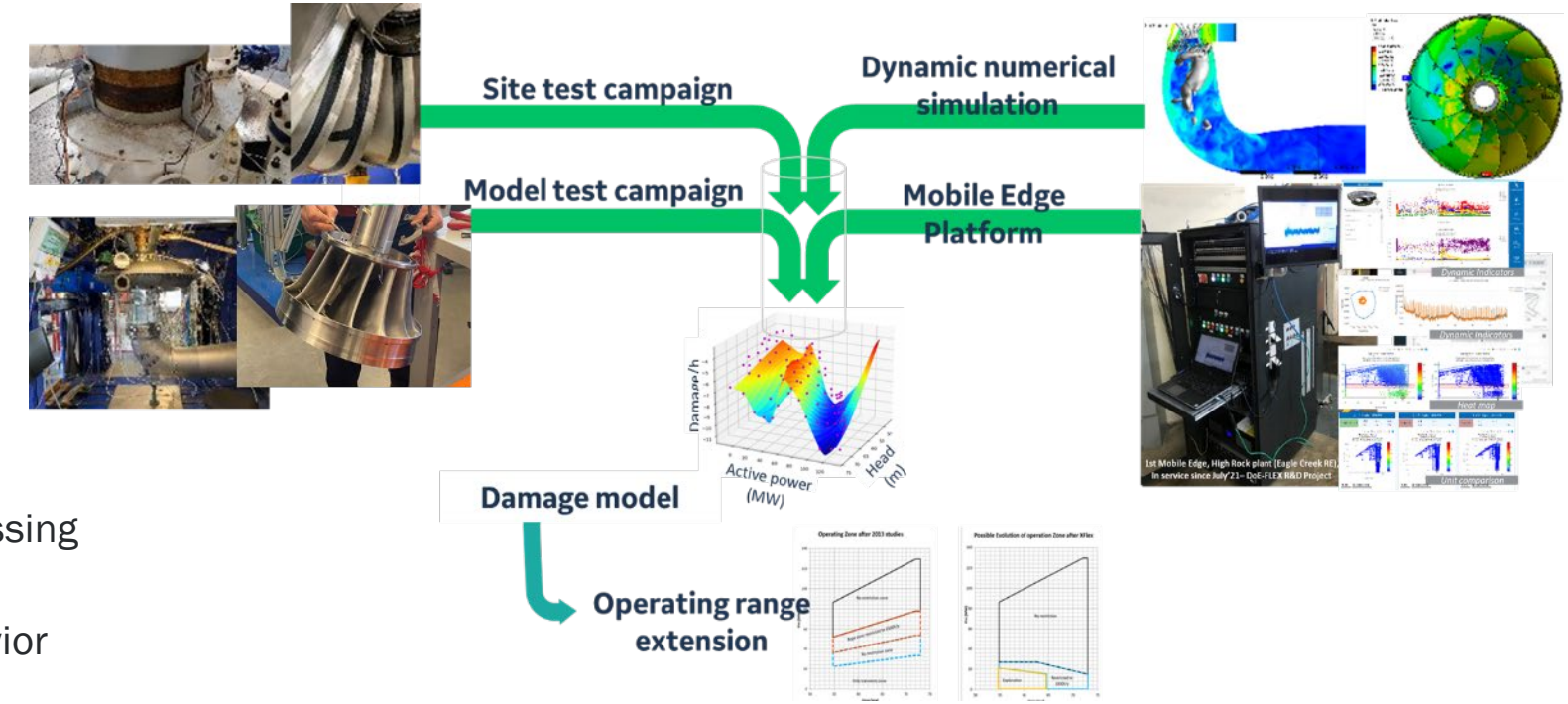


Efficiency (lines) and runner stresses (dots) over the operating range at a given head, with vs without air admission
(model tests, Jun.22)

- **Damage model** and **air admission management** drive the path to further operation optimization

Performance: Accomplishments and Progress

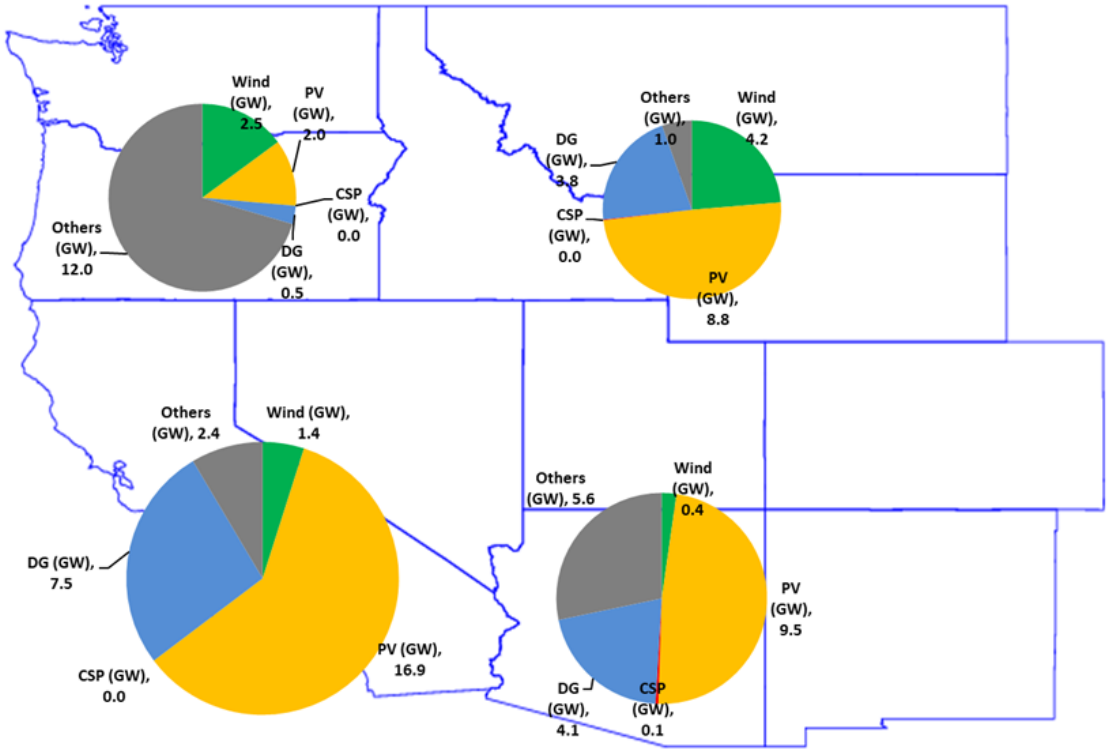
- Extensive & robust **methodology for operating range extension** of Francis-driven hydro-plants

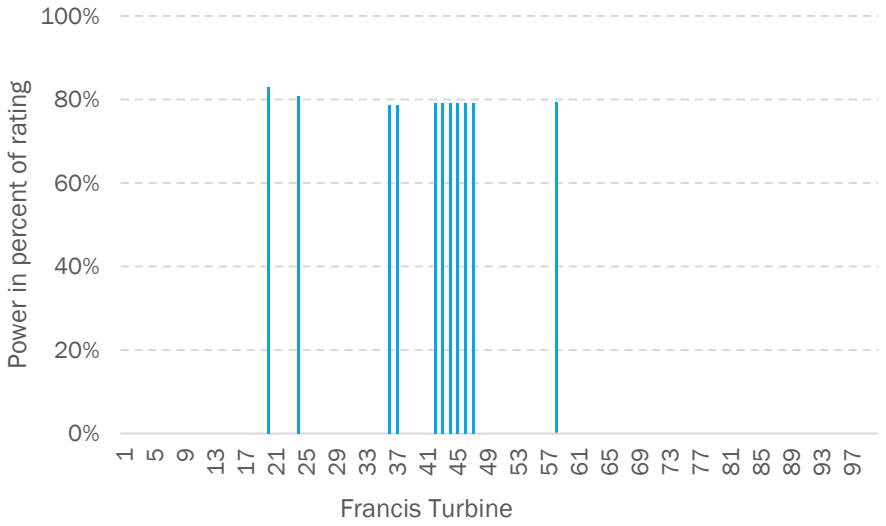


- Upgraded & innovative tools
  - **Temporary condition monitoring:** compact and mobile platform for data acquisition & HF Edge Processing
  - **Additive model runner:** ideal to assess the mechanical behavior during trials on hydraulic platform
  - **Damage model:** based on state-of-the-art fatigue damage calculation methods and extrapolation rules

- *Progress in the understanding of the correlations between each steps & tools will enable to define lighter approach, more widely deployable*

Base Case – 2028 light spring load with high wind and solar

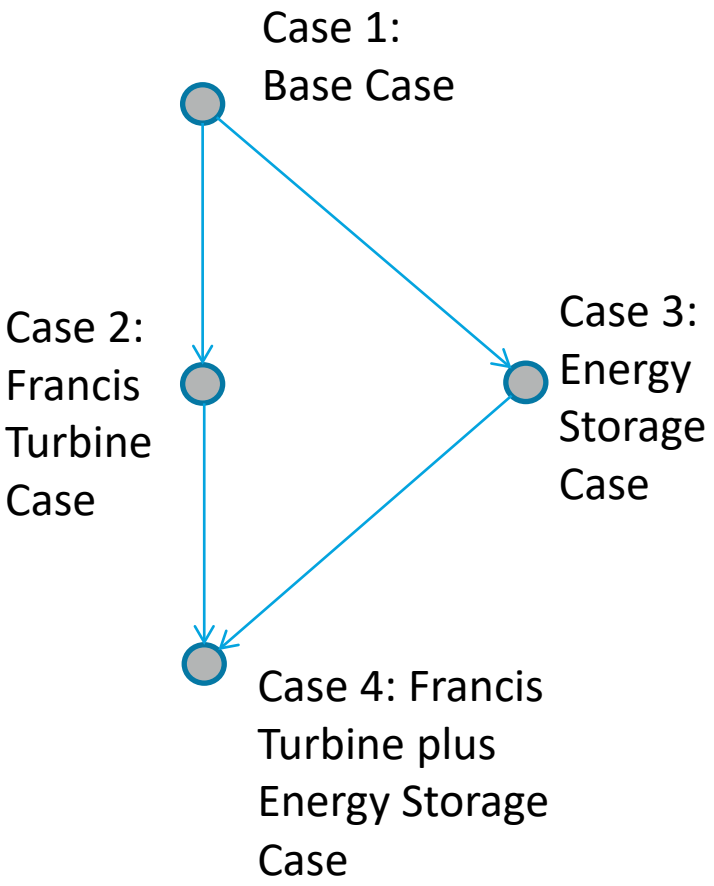




Power output in percent of rating for the selected low head Francis turbine units in Base Case

	WECC	CALIFORNIA	DSW	NORTHEAST	NORTHWEST	Non-US
Wind (GW)	16.0	1.4	0.4	4.2	2.5	7.4
PV (GW)	37.1	16.9	9.5	8.8	2.0	0.0
CSP (GW)	0.1	0.0	0.1	0.0	0.0	0.0
DG (GW)	19.5	7.5	4.1	3.8	0.5	3.6
Others (GW)	27.3	2.4	5.6	1.0	12.0	6.4
total (GW)	100.0	28.2	19.7	17.8	17.1	17.3
Penetration (%)	72.7%	91.5%	71.7%	94.6%	29.5%	63.2%

Evolution of Study Cases



Base Case - light spring condition with high wind and solar penetration

Francis Turbine Case – low head Francis turbine units added to the Base Case

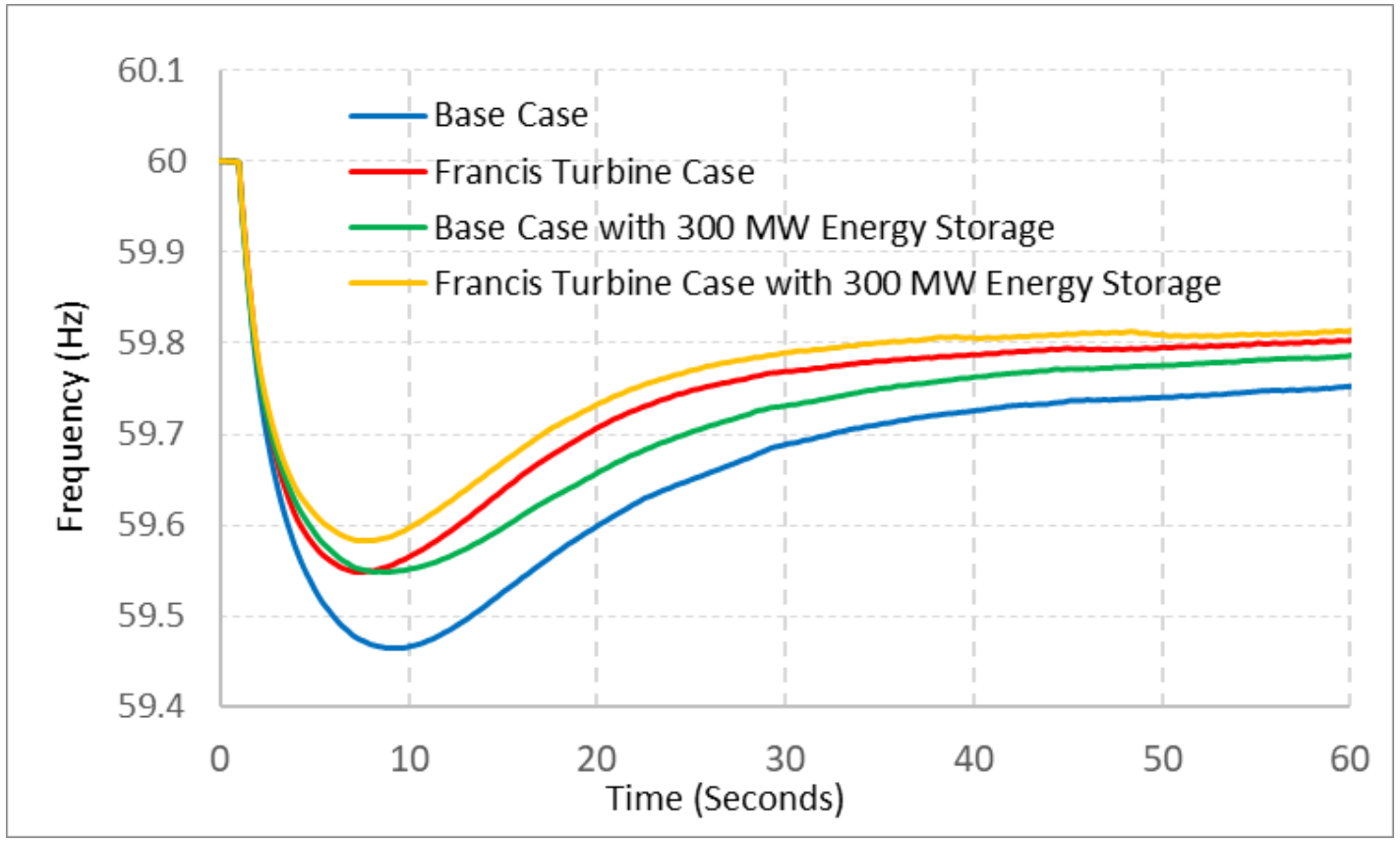
Energy Storage Case – Energy storage device added to the Base Case

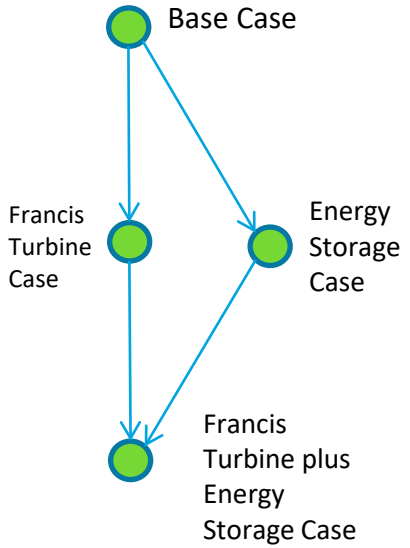
Francis Turbine plus Energy Storage Case - low head Francis turbine units online and Energy Storage added to the Base Case

Selected low head Francis turbine units

	Number of Francis Turbine	Generation Capability (MW)
California	9	366
Desert Southwest	10	431
Northeast	24	2010
Northwest	57	5359
WECC	100	8166

Frequency response to loss of two Palo Verde units – Combination of Francis Turbine and Energy Storage





Future Work

- Conclude & Inform
  - Q2-2022 Complete model test & Cross-check results from the various analysis
  - Q2-2022 Build the High Rock damage model & final operating range extension
  - Q2/3-2022 Final report & dissemination tools

- A potential follow-up is also under negotiation:

  Increasing Operational Flexibility of Existing Hydropower through Non-Intrusive Active Control and Hybridization, 2417-1509, Award Number: DE-EE0010187
  - Further investigate DE-EE0008942 results with sensitivity study, towards active control
  - Investigate indirect & non-intrusive methods to extend the applicability of the range extension process
  - Investigate operating range extension opportunities through hybridization with battery

Q&A